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AN ERGOMETER FOR MAXIMAL EFFORT REPETITIVE LIFTING

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ABSTRACT

A repetitive lifting (RL) device was designed to examine the physiological limitations to maximal effort RL. The device consists of a pneumaticly driven platform providing controlled lifting and lowering of loads to 100kg between infinately adjustable stops 0-200cm apart. The device has been used in two protocols and extensive pilot testing.

INTRODUCTION

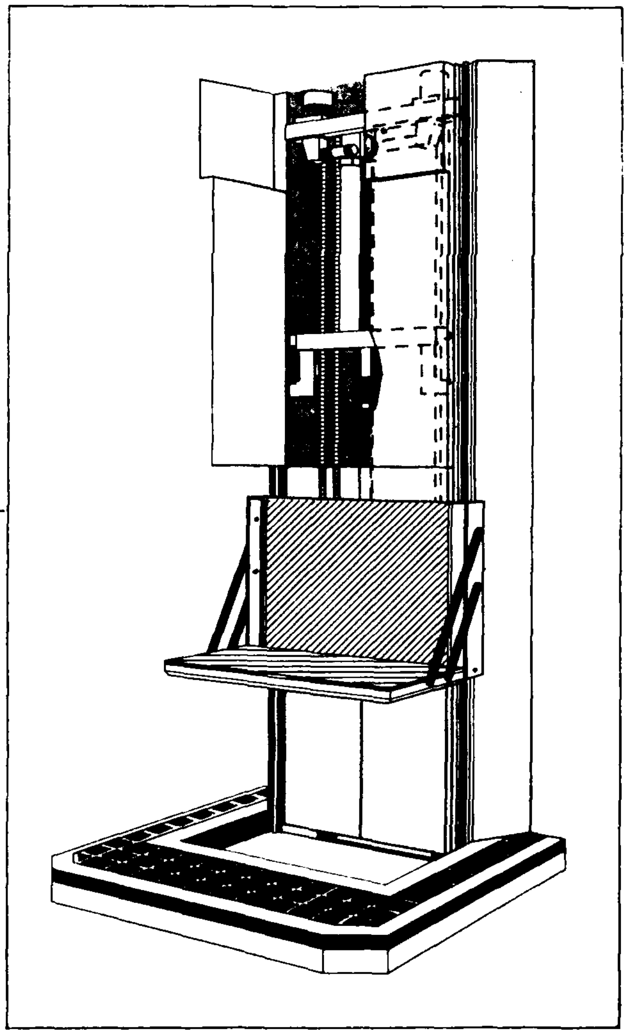
The vast majority of physically demanding jobs in the armed forces involve lifting. The success of a military mission often depends on the ability to manually move supplies and ammunition. In contrast to an industrial setting, the material handled frequently exceeds safe weight and size limits and must be lifted at a rapid rate for extended time periods. Considerable industrial lifting research has been performed to determine safe and acceptable workloads for repetitive lifting (RL), however little is known about, nor is equipment available to study, maximal effort RL. The purpose of this paper is to describe a RL device designed to examine the physiological limitations to RL, and to provide preliminary data on the maximal effort repetitive lifting capacity of soldiers.

METHODS

Instrumentation

The RL ergometer was based on a device reported by Snook and colleagues at Liberty Mutual Co.[1] It consists of a vertically moving shelf driven by a large bore, dual-acting pneumatic cable cylinder and is guided by two vertical 2.54cm chrome-steel linear bearing shafts. The shelf has an adjustable and controlled rate of lift as well as decent and can deliver loads ranging up to 100kg between two limit stops. These upper & lower stops are both individually adjustable, 0-200cm above the floor. Each stop is supported by a pair of 2.2m vertical 3/4" Acme threaded drive screws, turned by AC gearhead motors remotely controlled from the operator control panel. To prevent "creeping" during exercise periods, the drive screws were fitted with specially designed pneumatic caliper brakes. The stops may be changed or adjusted during exercise.

The user-paced device responds to the subject's lifting rate and an adjustable delay-of-shelf-movement from 0-5 seconds. As a load is placed on or removed from the shelf, a field proximity sensor detects the presence of the metal box and activates the device. This sensor is embedded in the 3cm thick A.B.S. plastic shelf, is not visible on the surface and is sensitive to non-ferromagnetic as well as ferrous metals. While the rate of lifting is limited by the distance the platform moves and the skill of the subject, skilled lifters moving a



weighted box from floor to shoulder height have achieved rates of 20 lifts/minute. This fast lifting rate using a moderate load was adequate to maximally tax most test subjects.

The operator control panel provides directional, distance, lift/lower and emergency stop controls as well as a digital exercise timer and a lift cycle counter. Timer and counter are automatically initialized at the beginning of the exercise period. Provision was made for a pause, or breaks in timing during extended exercise periods. Extensive measures were taken to guarantee the safety of human test subjects including a very sensitive continuous tapeswitch along the underside perimeter of the moving shelf to sense objects or parts of the anatomy in the path of travel and switches on the front access panels in case the subject falls forward while the shelf is in motion. All sharp corners were softened and pinch-points minimized. A wall anchoring system and extensive use of vibration-proofing materials resulted in a significant reduction of noise and vibration.

The device requires 117 volts AC, 125 psi $4ft^3$/min compressed air. A Teflon' coated aluminum box was fabricated for the lifting tasks. Box dimensions were 46.5 x 31 x 23cm with handles attached 15cm above the box bottom. A removable, partial containment grid was placed inside the box bottom to stabilize the iron shot weighting material. The empty box and grid weigh 7.8kg. Up to 100kg iron shot was available for loading.

Subjects

Eight healthy young males were recruited to participate in this study. Subjects were briefed, medically screened and signed an informed consent form. Physical characteristics of the subjects were (mean ± SD) age = 22.2 ±2.1 years, height = 175.6±9.8cm, weight = 76.1±9.8kg, treadmill $\dot{V}O_2$ max = 4.05±0.48 l/min and one repetition maximum lift to 132cm (1RM) = 68.1±13.5kg.

Lift Task

Some realistic examples of RL tasks that soldiers are required to do include loading supplies onto a truck or loading ammunition onto a gun platform for one hour at a relatively intense work rate. The model selected for study here was that of loading a standard Army 2-1/2 ton truck, with a bed height of 132cm. A metronome and digital display were used to pace the subjects at 6 lifts/min. A modified psychophysical approach was used. The subjects were trained to perform the lifting task on the RL ergometer for 3-1/2 weeks. Rather than asking subjects to choose the maximal acceptable weight, subjects were asked to choose the maximum tolerable weight they could lift to 132cm at a rate of six lifts/min for one hour. Eight 30 second weight adjustments were allowed at minutes 0,5,10,15,20,30,40 and 50. One of the methodological problems anticipated was that subjects would add weight toward the end of the hour and finish with a load they could not maintain for a full hour. In order to circumvent this problem and validate the weight selected, each subject was required to repeat the one hour lifting work using the final weight selected during trial one. Subjects were allowed at least 48 hours to rest between trials. Measures were collected every 10 minutes during the one hour lift task and included oxygen uptake ($\dot{V}O_2$), heart rate (HR), Rate of Perceived Exertion (RPE), load following each adjustment and number of lifts.

RESULTS

As is shown in Table 1, subjects worked at 54% of their treadmill $\dot{V}O_2$ max during the one hour task and lifted a load equal to 60% of their 1RM. A final RPE of 17 (very hard) would seem to substantiate a prolonged maximum effort. All subjects were able to complete the second one hour lifting task using the final load of the first bout. It appears then that subjects were able to select a load appropriate to the task without overestimating their capabilities as they neared the end of trial one.

The RL ergometer has demonstrated an ability to handle punishing loads at fast lifting rates. The device can be used in conjunction with other standard physiological measurements such as rate of oxygen uptake, heart rate and blood lactate analysis. It can also be used for all types of psychophysical methodologies or in the examination of maximal lifting heights, weights or rates. It has been used to develop a $\dot{V}O_2$ max procedure for repetitive lifting and has been used successfully in two major studies and extensive pilot testing. There have been no device-related injuries, and little down time due to mechanical failure during approximately 560 hours operating time.

Physiological Data Collected at the End of Each One Hour Maximal Effort Lifting Tasks

	Self-selected Load	Set Load
$\dot{V}O_2$ (l/min)	2.21 ± 0.19	2.21 ± 0.26
$\dot{V}O_2$ (ml/kg/min)	29.1 ± 3.7	29.0 ± 3.2
%$\dot{V}O_2$ max	54.2 ± 4.0	54.2 ± 4.0
Heart Rate (bpm)	171.7 ± 14.8	169.4 ± 15.6
Load (kg)	40.3 ± 7.7	
% 1RM	60.1 ± 11.2	
Watts	50.1 ± 10.5	51.4 ± 10.5
kJoules	28.6 ± 5.9	29.2 ± 5.8
RPE	17.0 ± 2.1	17.0 ± 2.1

No significant differences between the two trials on any measure

REFERENCES

1. Snook, S.H. and C.H. Irvine. Maximum frequency of lift acceptable to male industrial workers. American Industrial Hygiene Association Journal, 29(6): 531-536, 1968.